# SCIENCE FOR GLASS PRODUCTION

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## APPLICATION OF FIBERGLASS FRIT IN CONSTRUCTION ENGINEERING

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The use of fiberglass as a reinforcing material for fiberglass frit is discussed. The application areas of fiberglass frit and products made of this material are described. Problems on the strength of fiberglass frit depending on various factors are studied.

Fiberglass frit is a composite material in which high-strength glass fibers are joined by a matrix based on inorganic binders. The valuable technological properties of fiberglass frit include its high tensile and bending strength, crack resistance, impact load resistance, decreased water permeability, absence of the propensity for formation of shrinkage cracks, and high fireproof characteristics [1].

As distinct from the polymer-based composite materials, fiberglass frit has high resistance to fire, corrosion, and biologically active agents frequently encountered in ambient environment. Fiberglass frit does not contain compounds which are hazardous to the health of man or animals. Fiberglass frit reinforced with nonmetallic materials is not magnetic. The use of fiberglass frit allows for an effective solution of the problem of saving metal materials and human resources in construction engineering.

There are several types of fiberglass frit which are commonly used.

**Constructional fiberglass frit** by its mechanical characteristics is suitable for the production of structural elements functioning under a force impact in air or in water within the temperature range from – 60 to + 40°C.

The unidirectional fiberglass frit is produced from rovings, twisted glass filaments, and fiberglass rolled oriented materials. Cross-lateral reinforcement is implemented employing either unwoven glass nets or the materials used for unidirectional fiberglass frit which are arranged at prescribed disorientation angles. The fiberglass frit with a random arrangement of fibers in the reinforcement plane is made on the basis of chopped rovings by the spraying deposition method. The complicated reinforcement structure is due to the use of fabrics, woven nets, and knit-broached materials as reinforcing components. Textolite fiberglass frit is obtained in this way. Different variants of reinforcement are possible owing to the use of nonwoven and woven materials. The latter are used to reinforce the outer layers of the product.

When non-woven fiberglass materials are used, they comprise 8 – 30% of the composite weight, and woven materials comprise 10 – 50 wt.%.

**Waterproofing fiberglass frit.** Two varieties of waterproofing fiberglass frit have gained wide acceptance in construction engineering: the fiberglass frit with a random arrangement of fibers in the reinforcement plane and the textolite variety.

The fiberglass frit with the random arrangement of fibers in the reinforcement plane is used as a water-proofing material in ferroconcrete tanks for storing fresh or sea water, sewage, weak and fatty acids, wine, petrochemical products, and other liquids. The material in this case replaces the traditional waterproofing coatings and is distinguished by its high reliability, mechanized production technology, and rapidity of installation. Besides, this variety of fiberglass frit is successfully used as a substitute for the epoxy putty protective layer in settling basins and metallurgical sewage purification works.

The **textolite waterproofing fiberglass frit** is produced of woven glass nets, glass fabric or knitted and broached materials impregnated with a polymer-cement suspension based on alumina cements or Portland cements.

The heat-insulating fiberglass frit is autoclave-free foam concrete made of Portland cement employing a synthetic foam-forming agent dispersely reinforced with staple fibers.

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**Heat-resistant fiberglass frit.** All varieties of this fiberglass frit are incombustible and have higher refractoriness than the traditional construction materials. Therefore, they can be used as fireproof coatings and in the production of fireproof shields and structures.

The areas of application of fiberglass frit are as follows:

three-layer wall panels with outer fiberglass frit layers for residential and industrial buildings;

roof, workpieces for civil engineering, products for surface plastering;

assembled volume-block shelters at gas and oil mining fields;

fencing plates for balconies and bridges;

window-sill, drain and parapet boards to replace zinc-plated steel, ferroconcrete, and wood;

discharge chutes for sewage, manure removal, industrial sewage, and other purification facilities for agriculture and irrigation; to replace concrete;

livestock fountains and feed boxes for cattle farms;

panels for roofs without rafters in rurals buildings (to save the consumption of metal, wood, and other roof materials);

man-hole rings and lining plates for irrigation channels;

small-size architectural elements: flower beds, decorative elements in buildings; profiled sheets for fences, tents, etc.;

waterproofing coatings for multipurpose tanks and containers and large-diameter waterpipes;

corrugated sheathing made on pneumatic forms;

non-removable forms;

floors in public buildings;

replacement for asbestos-cement pieces;

internal and external pipelines;

fireproof elements: doors, walls, and insulating partitions;

seashore structures: pontoons, buoys, seaside embankments;

construction of small houses and fences;

small containers: cable cabinets, fire hydrant boxes, storing tanks.

glass tubes with protective sheathing;

glass frit ventilation skips, air ducts, and gas conduits that can replace zinc-plated facilities;

bathroom cabin partitions;

three-layer warmth-retaining ceiling panels;

ordinary and warmth-retaining cover casing to replace ferroconcrete structures.

**The use of chopped (crushed) fiberglass strands to reinforce cement mixtures.** Alkali-resistant fiberglass is cut into segments 12 – 15 mm long. These short strands are randomly distributed in cement mixtures for their reinforcement.

**The main methods for production of fiberglass frit are as follows:** mixing of components with their subsequent placement into a mold; contact molding; depositing of fiberglass frit components on a mold by spraying; winding; centrifuging; vibration immersion of fiber; vibration extrusion; wet molding.

The method of mixing the components (fiberglass and suspension) involves the employment of short glass filaments: staple fiber or chopped glass roving. In this case, it is rather difficult to accomplish the homogeneous distribution of strands in the cement matrix and preserve their straight linearity in the composite.

The chopped fiberglass (glass roving segments 25 – 30 mm long) is dispersed through mixing with a semidry cement mixture (water : cement ratio equal to 0.20 – 0.25) in high-speed mixers. After mixing, the wet fiberglass frit mixture is pressed in a mold. If molding is impossible, the mixture is diluted with water up to a required plasticity level, then placed in the mold and vibrocompacted. The use of short strands does not permit fiberglass frit to attain as high a tensile and bending strength, as in using continuous fiber in the form of cloth, netting, or canvas.

**Contact molding** is the least mechanizable technology of fiberglass frit production. The process consists in consecutive placing of fiberglass material layers and cement suspension into a mold and compression of each layer by facing or rolling using a riffled rubber roller.

**The spraying method** is a variant of the contact molding method in which the process of laying fiberglass (glass roving) and cement suspension is mechanized. This method makes it possible to eliminate the manual operations of cutting the reinforcing material and laying it in the mold, and to mechanize the deposition of the cement binder.

In using this method, chopped glass roving (segments 30 – 60 mm long) is introduced into the cement suspension employing a pneumatic trigger sprayer, and the contemporary equipment provides as well for the synchronization of the cement suspension feed with the fiberglass feed. The relatively low content of fiberglass (about 3%), the relatively short glass strands, and their random arrangement in the plane of reinforcement do not ensure the maximum strength for the fiberglass frit. However, this method is widely used in producing waterproofing and corrosion-resistant coatings and in manufacturing numerous articles.

**The winding method.** The products and structures which have the shape of the body of revolution are produced using the winding method. It can be used as well to obtain a structure resulting from cutting a body of revolution into several parts.

**The centrifuging method** is based on consecutive insertion of the layer of cement suspension and chopped glass roving into a chute feeder and feeding the mixture to a rotating mold to manufacture centrifuged fiberglass frit pipes. The wall thickness of these pipes can be a factor of 1.5 – 2 less than the wall thickness of ferroconcrete pipes.

**The method of fiberglass vibration immersion.** The impregnation of fiberglass with a cement binder can be accomplished by vibration, which is implemented as a special technology of fiberglass frit production. The method is suitable for making flat fiberglass frit elements.

This method is expedient if one needs to ensure a high content (20 – 25%) of fiberglass in the fiberglass frit, and makes it possible to operate with a decreased water:cement ratio in the binder (0.40 – 0.45).

**The method of bending structures in the wet state.** Some types of fiberglass frit structures of complicated configurations can be created by first producing flat elements and then bending these elements while in the wet state.

The bending method is expedient for such profiles as angles, channels, and corrugated, fibroform, and duct elements. The method is promising for industrial use.

**The method of secondary shape-forming.** The essence of the method consists in accomplishing the required shape and dimensions of a fiberglass frit structure as a consequence of the deformation (bending or unbending) of the intermediate fiberglass frit piece after its complete hardening. The method is based on the capability of fiberglass frit which contains a certain percent of reinforcement material to withstand substantial deformations in its elastic state without being destroyed.

**Additional strengthening of fiberglass frit.** There are two techniques which make it possible to increase the strength of fiberglass frit after molding and, accordingly, to improve the load-carrying capacity of the fiberglass frit structure. Both techniques can be summarized as a decrease in the porosity of structural fiberglass frit.

The final stage of the fiberglass frit production is its hardening. As distinct from concrete and asbestos cement, fiberglass frit should not be subjected to steam-curing, since the action of steam on fine glass fiber decreases the strength of the material. Due to its thinness, a fiberglass frit article under an incorrect hardening regime can be quickly dehydrated. Therefore, the stage of fiberglass frit hardening is extremely important. Violations of the hardening regime often causes failures in manufacturing fiberglass frit articles.

The optimum hardening conditions for fiberglass frit require 100% moisture and a temperature of 15 – 20°C. The molded article should be covered with a film or a wet cloth.

**Machining of fiberglass frit articles.** A solidified fiberglass frit workpiece can be subjected to drilling, sawing, and turning. Screws can be driven into fiberglass frit. In the wet state, the material can be cut by a knife.

The external surface of fiberglass frit structures depends on the quality of the forms. When fiberglass frit is molded on a glossy surface (plastic or film), it acquires a mirror-like surface with white veins of glass filaments.

Fiberglass frit elements can be joined to each other or to other materials: by agglutination of a fiberglass frit strap; using steel anchors and filling parts; by bolts and rivets; by synthetic resin adhesives.

**Classification of fiberglass frit structures and articles, and their application areas.** By their purpose, the fiberglass frit articles and structures are subdivided into seven groups: self-carrying; non-carrying; heat-insulating and soundproof; waterproofing and atmosphere-proof; decorative and sculptural; special purpose; and structures with combined reinforcement.

**The self-carrying fiberglass frit structures** are most expedient as thin-walled spatial structures, as enclosures of positive or negative curvature; hanging structures; straight linear structures with the duct, corrugated, T- or Π-shaped section; containers of different shapes.

In designing self-carrying fiberglass frit structure it should be remembered that they have to be thin-walled: from 6 – 8 to 30 – 35 mm. Within these limits, the technical and economic advantages of the structures and the physicomechanical properties of the material are used with the maximum effect.

**The non-carrying fiberglass frit structures** and articles are conveniently used as thin-walled enclosures and various purpose partitions (including the assembled partitions on industrial premises and bathroom cabin partitions); fencing of balconies and staircases; suspended ceilings and suspended wall panels in dwellings, public, and industrial buildings; park architecture and small architectural forms; assembled parts of small-scale mobile facilities, such as summer camp cabins, workers' cabins, ventilation ducts.

The fiberglass frit for the specified purposes has a thickness of 5 – 20 mm.

**Heat-insulating and sound-proof fiberglass frit structures** and articles are elements made of heat-insulating and soundproof fiberglass frit, for example, blocks or panels of different sizes with a density of 250 – 700 kg/m$^3$ used as floor and ceiling heat-insulation.

The three-layer heat-insulating structure is a combination of structural and heat-insulating fiberglass frit in a single structural element.

The strength of fiberglass frit articles depends on many factors, such as the strand length, the reinforcement content, its orientation, the manufacturing technology, etc.

Fiberglass frit loses its strength with time. The loss of strength occurs quickly in the first two or three years. After that, this process is sharply reduced. Owing to the high initial strength of the fiberglass frit material (25 – 40 MPa bending strength and 10 – 15 MPa tensile strength), the strength of this material in service is sufficient to allow its application in civil engineering [2].

The theories predicting the mechanical properties of cement composites are usually reduced to the calculation of such factors as fiber-fiber interaction, the length and orientation of the fiber and the surface crack.

There are several possible ways for destroying a composite material, including the destruction of the matrix or the fiber in stretching, pulling out fibers, and destruction of fibers due to their substantial amount of defects. In order for the fibers to be pulled out, their length has to be below a critical value. An increase in the ratio between the fiber length and its diameter, an increase in the fiber length, and its part by volume in the material usually result in increased tensile and bending strength [3].

The prevailing mechanism of destruction in a fiberglass frit composite is pulling out fibers. In the case of destruction of the fiber, the composite material will be destroyed at the moment of rupture of the fiber. Pulling out or sliding of the fiber in the contact zone can take place if the fiber is below a certain critical length.

Fibers in most composites are not oriented in parallel with the applied stress direction, and the reinforcement effect is not complete. The fibers arranged perpendicularly to the applied stress absolutely or almost do not contribute to increasing the strength of the composite.

With a high volume content of the fiber in the composite, the adhesion strength will be insufficient, due to the increased matrix strength and poor distribution and wetting of the fiber.

The tensile and bending strength of cement reinforced with fiberglass even after 10 year of storage in air at a temperature of 20°C and 40% moisture can exceed several times the strength of non-reinforced cement.

An increase in the fiber length and volume content complicates the mixing process and results in decreased strength of the composite. In order to ensure increased bending strength, it is usually necessary to sacrifice the compressive strength, which is decreased by nearly 20% for paste with a low water/cement ratio, and for a higher value this ratio decreases by 30%.

There currently are two main methods for fiber reinforcement of cement: directed and random. The directed reinforcement provides for using oriented fiberglass reinforcement in the form of filaments, woven and nowoven fabrics, bands, and rods. Sometimes discrete reinforcing segments are arranged directionally as well. The reinforcing elements can be joined in bundles and bands by synthetic resins.

Below, it follows that the evaluation of the tensile strength of the composite material depends on the fiber distribution in the matrix, whereas the strength of the material with unidirectional fibers is conventionally taken as 100%.

| Fiber distribution | Conventional strength, % |
|---|---|
| Unidirectional | 100 |
| Netting | 45 – 50 |
| Random: | |
| two-dimensional | 30 – 37 |
| three-dimensional | 0 – 20 |

The reinforcing effect in the random distribution of reinforcement is lower than in the unidirectional distribution, however, the randomly reinforced concrete is more technologically effective and has isotropic properties.

It is established that the initial fiber length which ensures the preservation of the fiber as a strand has to exceed 30 mm. At the same time, the satisfactory anchoring of the fiber (at which the destruction of the composite occurs with rupture of the majority of the fibers) was attained when the fiber length was 45 mm. The use of a fiber longer than 45 mm deteriorated the mechanical properties of fiberglass concrete, due to the increased inhomogeneity of its structure.

Correct selection of the diameter of the fiber reinforcing fiberglass frit articles makes it possible to ensure not only high strength parameters of the composite material, but its long service as well. On the one hand, the use of the thinnest possible fiber ensures the highest bending strength and shock viscosity, the volume content of the fiber being equal; on the other hand, the larger the fiber diameter, the longer the fiberglass will preserve its reinforcing capacity, since any fiberglass is damaged to some extent under the effect of the liquid phase of the hardening Portland cement stone.

The experimental results revealed that after two years of storing the bending strength parameters of samples with various fiber diameters are close, and the residual strength parameters are equal. The specific impact strength of the fiberglass frit reinforced with fibers of diameters 14±3 and 17±3 μm exceeds that of the sample with a thinner fiber. Apparently, the use of a fiber over 11 μm in diameter makes it possible to obtain fiberglass frit whose impact strength persists at a higher level for a longer period [4].

The effect of the fiber length and the fiber content on the fiberglass frit properties was investigated using composite materials based on cement reinforced with alkali-resistant fiberglass 10 – 40 mm long (2 – 8 vol.%). The best parameters after 28 days of hardening were exhibited by the fiberglass frit with 6% fiber additive. Its bending strength increased 4 – 5 times, as compared to the strength of the non-reinforced cement stone, its bending strength increased 3 – 4 times, and the impact strength increased 15 – 20 times. A further increase of the fiber content in the composite material increases its porosity, and as a consequence, the bending strength and the tensile strength of the fiberglass frit are decreased. The stress and deformation withstood by the composite at the moment of matrix destruction increase as the fiber content increases. No perceptible improvement of the module characteristics of the composite was observed on introduction of the fiber. The main properties of fiberglass frit are affected by the fiber content and length, as well as by the hardening conditions of the composite which are related to the degree of cement hydration and the variation in the composite porosity at the fiber/matrix interface.

In industrial production, certain deviations from the prescribed technological conditions often occur. These deviations in the production of fiberglass frit articles are numerous enough: nonuniform fiber distribution, fiber clotting, nonuniform compaction of composite material, etc. The optimum fiber content for the fiberglass frit articles produced by the spraying-suction method is around 6%. The fiber length has to be below 40 mm.

The tensile and bending strength of fiberglass frit and its impact strength are higher for articles hardening in air than for articles hardening in water. The cement which hardens in water hydrates to a higher extent, and the hydration products fill the vacancies in the matrix the same way as in the fiber strands.

The corrosive action of cement on fiberglass is less perceptible during storage in air, as a consequence of which the reinforcement retains the greater part of its initial breaking strength.

The impact strength of fiberglass frit increases as the fiber length and the fiber content increase.

**Special requirements to cement-resistant fiberglass.** Fibers with traditional compositions (E-glass, for instance) easily disintegrate in the alkaline medium of Portland cement. As a consequence, the additional strength of the cement containing such fibers is soon lost.

The development of fiberglass frit production technology and its successful use in construction became possible only after special fiberglass was developed which can withstand the aggressive action of the highly alkaline medium of the hardening Portland cement stone.

The experiments performed in our country and abroad established that the main group of cement-resistant glasses consists of alkaline zirconium-bearing glasses ($SiO_2 - ZrO_2 - Na_2O$ system). The higher the content of $ZrO_2$ in glass, the higher its chemical resistance, all other conditions being equal. However, experience shows that the application of compositions in which the $ZrO_2$ content exceeds 17 wt.% is not advisable.

The main glass compositions recommended for industrial use belong to this system. For example, the widely known Cem-fill fiberglass is based on alkaline zirconium-bearing glass. Two fiberglass brands Shch-15-ZhT and STs-6 developed at the GIS joint-stock company and put into production are also based on glasses of the $SiO_2 - ZrO_2 - Na_2O$ system. Comparative tests of cement resistance of the fibers based on different glasses demonstrated that the corrosive resistance of glasses not containing zirconium is much lower than the same parameters in zirconium-bearing glasses, and that the use of the former as a reinforcing component in materials based on Portland cement is inadmissible.

Thus, zirconium-containing glasses are used to produce cement-resistant fiberglass both in Russia and abroad, since they provide for the retention of good physicomechanical parameters in fiberglass frit.

Another important issue is the physical state of the fiber which can be used for disperse reinforcement of composite materials based on inorganic binders, in particular, Portland cement.

As for the physical state of fiberglass for cement reinforcement, the opinions of foreign researchers coincide: it ought to be dispersible glass roving, i.e., when chopped, the fiber should split into complex glass strands. The reinforcing element is a complex strand consisting of a certain number (most often, 200) of elementary filaments.

It was found that the use of staple fiberglass is not advisable. This is due to the fact that the introduction of the monofiber to the cement matrix does not allow for reinforcing more that 1.5% of the cement mass, and this amount does not provide for an effective increase in the strength of the article. It is only through employment of the complex strand that makes it possible to introduce 3 – 8% fiber and to accomplish the required strength increase.

The longevity of fiberglass frit articles is one of its most significant properties for the development of new construction materials.

The test results indicate that the strength of fiberglass frit samples has a tendency to decrease, but this decrease in strength becomes less intense with time. Thus, samples stored in natural conditions for three years exhibited a decrease in strength by 30%, and after two subsequent years, the strength decreased only by 5%.

The smaller the complex strand fiber diameter, the higher the temperature of the aggressive medium; and the lower the chemical resistance of glass, the sooner the initial strength decreases.

The main Russian developer of cement-resistant fiberglass is the GIS JSC. Fiberglass of grades Shch-15ZhT and STs-6 was manufactured on the MOSZ GIS experimental production plant whose capacity was around 100 tons per year. At present, an industrial facility for producing cement-resistant fiberglass has been put in operation at a glass factory in cooperation with the Laboratory of Cement-resistant Fiberglass at the GIS joint-stock company.

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